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Document Name: SAE J1063: Cantilevered Boom Crane Structures--Method of Test

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(R) CANTILEVERED BOOM CRANE STRUCTURES —METHOD OF TEST—SAE J1063 NOV93

SAE Standard

Report of the Off-Road Machinery Technical Committee, Subcommittee 17, approved January 1974, and reaffirmed October 1980. Completely revised by the SAE Off-Road Machinery Technical Committee SC31—Cranes and Lifting Devices, November 1993. Rationale statement available.

1. Scope—This SAE Standard applies to mobile, construction-type lifting cranes of the cantilever boom type (Figure 1). Questions and comments regarding application or interpretation of the provisions in this test method should be referred to the originating SAE Committee.[1]

1.1 Purpose—The purpose of this test method is to provide a systematic, nondestructive procedure for determining the stresses induced in cantilevered boom crane structures under specified conditions of static loading through use of resistance-type electric strain gages, and to specify appropriate stress levels for specified loading conditions. Further, a 25% overload test is included to prove the overall structural integrity of the structure.

2. References

2.1 Applicable Documents—The following publications form a part of this specification to the extent specified herein.

ASTM E 251-67—Test Methods for Performance Characteristics of Bonded Resistance Strain Gages

Joseph Marin, "Mechanical Behavior of Engineering Materials," Englewood, N. J.: Prentice-Hall, Inc., 1962

"Guide to Design Criteria for Metal Compression Members," Column Research Council, Cushion Mallory, Inc., Ann Arbor, Michigan, 1960

2.2 Definitions

2.2.1 STRAIN (ε)—Deformation of material caused by weight and applied loading, quantitatively stated as unit change from an original dimension in meters per meter (m/m) (in/in).

2.2.2 STRESS (S)—The intensity of internal force accompanying strain, expressed in pascals (Pa) (psi). For purposes of this test method, stress is related to measured strain by the uniaxial stress equation:

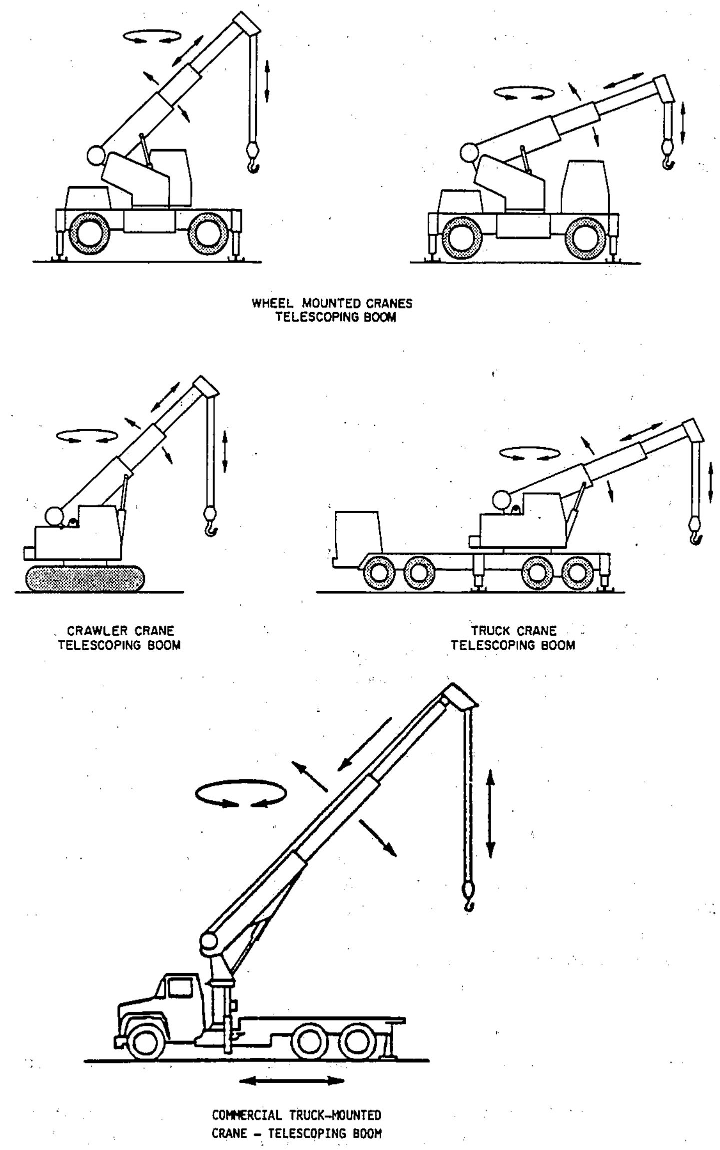
$$S = E \cdot \varepsilon \text{ (within the proportional limit)} \quad \text{(Eq.1)}$$

where:

S = stress, Pa (psi)
E = modulus of elasticity, Pa (psi) for the material involved (see 8.5)
ε = strain gage reading, m/m (in/in)

NOTE—The simple uniaxial stress formula may be insufficiently accurate for some areas of crane structures under biaxial stress and special consideration should be given in such cases. (See 8.1.1.)

[1] Chairman, Subcommittee SC31, ORMTC, Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096-0001.



The boom may have a basic boom structure of two sections (upper and lower) between which additional sections may be added to increase its length, or may consist of a base boom from which one or more boom extensions are telescoped for additional length. These are some typical configurations.

FIGURE 1—TYPICAL CONSTRUCTION-TYPE CRANES

2.2.3 YIELD POINT (S_y)—The stress at which a disproportionate increase in strain occurs without a corresponding increase in stress. For purposes of this code, yield point is to be considered as the minimum yield point or yield strength specified by the appropriate standard or by manufacturer for the material used.

2.2.4 CRITICAL BUCKLING STRESS (S_{cr})—The average stress which produces an incipient buckling condition in column type members. (See 8.3.1.)

2.2.5 INITIAL REFERENCE TEST CONDITION—The defined no stress or zero stress condition of the crane structure after "break-in" (see 6.3) as established by:

a. Supporting the structure on blocking to minimize the effects of gravity; or
b. The crane structure components in an unassembled state, or any alternate method that will establish the zero stress condition. Under this condition, the initial reference reading for each gage is obtained, N_1.

2.2.6 DEAD LOAD STRESS CONDITION—The completely assembled crane structure on the test site and in the specified position or attitude, ready to accept or pick up the specified live load. Under this condition the second reading for each gage is obtained, N_2.

NOTE—In determining N_2, the weight of hook, block, slings, etc., is considered as live load and should be resting on the ground or supported by a structure other than the crane.

2.2.7 DEAD LOAD STRESS (S_1)—The stress computed as defined in 2.2.2, by using the difference in the readings obtained in 2.2.6 and 2.2.5 for each gage, ($N_2 - N_1$).

2.2.8 LIVE LOAD STRESS CONDITION—The completely assembled crane structure on the test site and in the specified position or attitude, supporting the specified live load. Under this condition the third reading for each gage is obtained, N_3.

2.2.9 LIVE LOAD STRESS (S_2)—The stress computed as defined in 2.2.2, by using the difference in the readings obtained in 2.2.8 and 2.2.6 for each gage, ($N_3 - N_2$).

2.2.10 RESULTANT STRESS (S_r)—The maximum stress induced in the structure as a result of dead load stress (S_1) or the algebraic sum of dead load stress (S_1) and live load stress (S_2), whichever is greater.

2.2.10.1 Resultant average stress (S_{ra})—The direct compression stress in a column or the average stress computed from the several gages loaded at the section. (See 8.3.1.)

2.2.10.2 Resultant Maximum Stress (S_{rm})—The maximum compression stress in a column computed from the plane of buckling, as established from the several gages located at the section. (See 8.3.1.)

2.2.11 LOADINGS—The application of weights or forces of the magnitude specified under the conditions specified.

2.3 Symbol Nomenclature Summary

DL	= dead load stress, Pa (psi)
E	= modulus of elasticity, Pa (psi)
G	= modulus of rigidity (shear), Pa (psi)
JL	= jib length, m (ft)
K	= effective length factor for column
L	= unbraced length of column, m (in)
Lb	= length of boom, m (ft) (see 8.6.1 and 8.6.2)
Lj1	= length of jibs or extensions, m (ft) (see 8.6.2)
Lj2...Ljn	= length of additional jibs or extensions, m (ft) (see 8.6.2)
LL	= live load stress, Pa (psi)
n_1	= strength margin, Class I area, ratio of yield strength to resultant or equivalent stress
n_2	= strength margin, Class II area, ratio of yield strength to resultant or equivalent stress
n_3	= strength margin (derived from an interaction relationship) in Class III areas
N_1	= gage reading at initial reference test condition (zero stress condition)
N_2	= gage reading at dead load stress condition
N_3	= gage reading at live load stress condition
r	= radius of gyration of cross section, m (in)
RR	= rated radius, m (ft)
RL	= rated load, kg (lb)
S	= stress, Pa (psi)
S_1	= dead load stress, Pa (psi)
S_2	= live load stress, Pa (psi)
S_{cr}	= computed critical buckling stress for axially loaded compression elements, Pa (psi)
SL	= side load, kg (lb)
SLL	= side load, left, kg (lb)
SLR	= side load, right, kg (lb)
S_p	= stress at effective proportional limit, defined as $S_y - S_{RC}$, Pa (psi)
S_r	= resultant stress, Pa (psi)
S_{ra}	= resultant average stress computed from several gages at one section, Pa (psi)
S_{RC}	= maximum residual stress in compression, Pa (psi)

S_{rm} = maximum compression stress in a column computed from plane of buckling as established by several gages at one section, Pa (psi)
S_y = stress at yield point, Pa (psi)
S' = equivalent uniaxial stress, Pa (psi)
t = horizontal distance from the load center to the front pad reaction center for each boom section under consideration, m (ft)
v = Poisson's ratio
α = boom elevation angle, degrees
β = jib offset angle, degrees
ε = strain, m/m (in/in)
ε_a = strain recorded from leg "a" of rosette
ε_b = strain recorded from leg "b" of rosette
ε_c = strain recorded from leg "c" of rosette
ε_d = strain recorded from leg "d" of rosette
ε_x = maximum principal strain
ε_y = minimum principal strain
θ = direction of principal stress, deg
μ = units of strain, 10^{-6} m/m (in/in)
v = Poisson's ratio
σ_o = tensile yield stress, Pa (psi)
σ_x = maximum principal stress, Pa (psi)
σ_y = minimum principal stress, Pa (psi)
τ_o = shear yield stress, Pa (psi)

3. Limitations

3.1 This method applies to load-supporting structures as differentiated from power transmitting mechanisms. It is restricted to measuring stresses under static conditions, and a general observation after overload conditions. This method does not apply to lift capacity on tires.

3.2 Personnel competent in the analysis of structures and the use of strain-measuring instruments are required to perform the tests.

4. Method of Loading

4.1 **Suspended Load**—The specified load suspended at the specified radius and held stationary a few inches off the ground while strain readings are taken.

NOTE—The weight of the hook, block, slings, and rigging is considered as live load and shall be included as part of the specified suspended load. Hoisting rope is not considered part of live load.

4.2 **Side Load**—When the test condition requires side load, this load shall be applied horizontally and normal to the plane containing the axis of superstructure rotation and the centerline of the undeflected boom. Use manufacturer's specified reeving, and with the hoist line leaving the drum from an arbitrary position, the side load shall be applied as 3% (0.03 RL) in each direction, with the boom over the end of the machine, record N_3 for each direction. (See 2.2.8 and note in 7.4.4.)

NOTE—Side loading is applied to simulate the dynamic effects associated with machine operation including a 9 m/s (20 mph) wind loading that may be encountered.

4.3 **Deadman Load**—Deadman loading may be used, but caution must be exercised to assure accurate simulation of live load testing, especially with respect to side loads. Positioning with this system is difficult. Deadman loading is not acceptable for tests 3, 4, 6, 7, and 8 in Table 1.

5. Facilities, Apparatus, and Material

5.1 A concrete or other firm supporting surface, sufficiently large to provide for unobstructed accomplishment of the tests required. Where tests are to be performed on crawler tracks, the machine shall be level within 0.25% grade.

5.2 Means to measure levelness of the axis of the boom foot; accuracy 0.1% of grade.

5.3 Means for determining the load radius to an accuracy of ±1% not to exceed 0.2 m (6 in).

5.4 Means for producing transverse displacement of the suspended load and means for measuring the magnitude of the displacing force; accuracy ±3% of measured force.

5.5 **Strain Gages, Cement, Waterproofing Compounds, and Other Necessary Gage Installation Equipment**—Temperature-compensated strain gages designed for bonding to the materials to be tested shall be used. The gage factor shall have a tolerance within ±1%, gage resistance shall have a tolerance within ±0.3% for single element gages and ±0.4% for multielement gages. Gage testing must conform with ASTM E 251-67.

5.6 **Strain Indicating or Recording Instruments**—It is the intent that commercially available, high quality, reliable instruments be used in the performance of this test. Accuracy of the indicating instrument or the recording system shall be determined to be ±2% over the range of 0 to 3000 μ (m/m) (in/in) strain (determined in suitable increments). Calibration may be accomplished by electrical shunts or by precalibrated strain bar.

6. Preparations for Test

6.1 **Structure Analysis**—Make an analysis of each structure sufficient to locate critically stressed areas. These may include uniformly high-stressed regions as well as points of stress concentration. (See 8.2.) Brittle lacquer may be used as an aid in gage placement.

6.2 Perform a detailed inspection of crane to insure that all mechanical adjustments and condition of load-supporting components conform to manufacturer's published recommendations. Check that the crane is equipped in compliance with the test specification.

6.3 A previously unworked crane should be given a "break-in" run at or near the anticipated test loadings to mechanically relieve residual stresses that may have developed during manufacture and to minimize the possibility of "gage zero shift" during the test.

6.4 Disassemble the crane structure to the state required for inspection and strain gage installation. A thorough inspection after the "break-in" may reveal areas of high stress (yield) as evidenced by paint checking, scale flaking or other indications of permanent deformation not revealed by prior analysis (see 6.1).

6.5 Bond strain gages at the points determined by prior analysis (see 6.1) and any areas selected as a result of the inspection conducted in 6.4. Only competent personnel using proved materials and practice may be employed to insure that gages are of the correct type, properly oriented, and securely bonded to measure strains correctly.

6.6 Determine minimum yield strength and the modulus of elasticity (see 8.5) for the material at each gage location by referring to the material certifications or applicable standards. Determine critical buckling stress where applicable (see 8.3.1). Record these values on the test data summary sheet (see Section 9).

7. Test Procedures and Records

7.1 **Final Test Preparation**

7.1.1 Locate the machine on the test course and lock travel brakes and latches. Level the machine within 0.25% grade in the unloaded condition by shimming or by jacking. Do not relevel after the load has been applied to the machine.

NOTE—If test is for operation on outriggers, jack the crane to a position where all the tires or tracks are unloaded, unless some other conditions are required by the manufacturer's rating chart.

7.1.2 Connect strain measuring system and calibrate (see 5.6). Correct any malfunctions.

7.2 **Zero Stress Condition**—Position the crane (superstructure, boom) in the initial reference test condition(s) (see 2.2.5, item a) and obtain these readings.

7.3 **Dead Load Stress Condition**

7.3.1 Set the upper structure to the specified position relative to the lower structure if different than 7.2. Set swing brake or latches.

7.3.2 Set boom angle (and boom length) to develop specified load radius.

7.3.3 Read all strain gages for dead load stress condition (see 2.2.6). Compute the dead load stress (S_1) at each gage (see 2.2.7) and record on the test data sheet (see Section 9).

NOTE—A new dead load stress condition is established each time the position, attitude, or configuration is changed to suit specified tests and operations; therefore, 7.3.1 to 7.3.3 must be repeated for each new condition.

7.4 **Live Load Stress Condition**

7.4.1 Prepare a test load which weighs within ±1% of the specified load. Include the weight of the hook or lower block, slings, and other auxiliary equipment as part of the load.

7.4.2 Suspend the specified test load (see 4.1) and adjust boom angle (if necessary) to obtain the rated load radius. Apply the specified side load (4.2).

7.4.3 Read all strain gages for live load stress condition (see 2.2.8). Compute the live load stress (S_2) at each gage (see 2.2.9) and record on the test data summary sheet (see Section 9).

TABLE 1 - CANTILEVER BOOM CRANE TESTS

Test No.	Test Conditions Select	Apply	Purpose is to Test	Tested Components and Strength Margins Carrier	Super-structure	Boom and jib	Suspension (except rope)
1	Max (RR x RL) with largest rated load allowed at this load moment	RL and position superstructure in allowed rotation range to obtain maximum strain in member tested	Outrigger and carrier frame for maximum live load moment				
	a.Over end			Y	Y	---	---
	b.Over side			Y	---	---	---
2	Max (RR x RL) with longest boom at this load moment	a. RL and side load	Telescopic boom overlap effects, hoist or suspension system, superstructure and turntable bearing system	--	Y	Y	Y
		b. 1.25 RL or tipping load, whichever is less, over end	Boom buckling, hoist cylinder, or suspension system	---	Z	Z	Z
3	Max boom length, then max (RR x RL)	a. RL and side load	Telescopic boom overlap effect	---	---	Y	Y
		b. 1.25 RL or tipping load, whichever is less, over end	Boom buckling and side bending effect	---	Z	Z	---
4	Max boom length then min attainable RR	a. RL and side load	Side bending of boom, side load effect on superstructure	---	Y	Y	Y
		b. 1.25 RL or tipping, whichever is less, over end	Extension cylinder buckling, boom bending effect, hoist cylinder buckling, or suspension system	---	Z	Z	Z
5	Max numerical load, then shortest boom and min (RR)	a. RL and position superstructure in allowed rotation range to obtain maximum strain in member tested	Boom point integrity, foot pin force, outrigger and carrier frame.Turntable bearing system	Y	Y	Y	---
		b. 1.25 RL or tipping, whichever is less	Suspension system	Z	Z	Z	Z
6	Max (jib RL x JL x cos [α - β]), then longest boom and jib specified	a. RL and side load	Integrity of jib, boom point, and boom top section	---	---	Y	Y
		b. 1.25 RL over end, or tipping whichever is less		---	---	Z	Z
7	Max (jib RL x JL x sin β) then longest boom specified	a. RL and side load	Torsional effects of jib offset on boom and jib	---	---	Y	Y
		b. 1.25 RL over end or tipping, whichever is less		---	---	Z	Z
8	Max boom angle, max boom length, max specified jib at minimum offset	a. RL and side load	Integrity and stability of jib and boom	---	---	Y	Y
		b. 1.25 RL over end or tipping, whichever is less		---	---	Z	Z
9	Max allowable RL with boom extended 1 to 3 in (25 to 76 mm) at min RR	1.25 RL over end or tipping, whichever is less	Boom extension cylinder attachments	---	---	Z	Z
10	Max (RL x t) for each section. With the largest rated load allowed at this load moment	a. RL and side load	Bending effects on manual and powered sections at random boom angles and section extension	---	---	Y	---
		b. 1.25 RL over end or tipping, whichever is less		---	---	Z	---
11	Maximum Auxiliary Outrigger Load	a. RL	Auxiliary outrigger and carrier frame integrity	Y	---	---	---
		b. 1.25 RL or tipping		Z	---	---	---

7.4.4 Release side load and suspended load, returning crane to the dead load stress condition (see 7.3.3). Read all strain gages and compare with readings taken under 7.3.3. If the deviation for any gage exceeds $\pm(0.03\ S_y/E)$ m/m (in/in), check to determine the cause, correct, and repeat all procedures until consistent readings are obtained.

NOTE—Since temperature changes and the loading from even a moderate wind on long booms affect strain gage readings, testing should be done under as favorable atmospheric conditions as possible; position the machine so wind loading does not reduce the stress induced by side loading.

7.5 Compute the resultant stress (S_r) for the combined dead and live load stresses (see 2.2.10), and record on the test data summary sheet (see Section 9).

7.6 Thoroughly examine the crane for any observations which suggest a possibility of plastic deformation or other damage having occurred during the test.

7.7 Overload Test Condition—Structural integrity only.

7.7.1 Repeat 7.1.1 if applicable.

7.7.2 Position the crane (upper structure, boom) in the specified test position.

7.7.3 Set boom angle (and boom length) to develop the specified load radius and record dead load readings for Class IV gages.

7.7.4 Prepare the test load (see 7.4.1).

7.7.5 Suspend the specified test load and adjust boom angle (if necessary) to obtain the rated load radius.

7.7.6 Observe the performance of the structure and note any evidence of possible failure.

7.7.7 Release suspended load and return crane to dead load stress condition. Record dead load readings for Class IV gages. (See 7.4.4.)

7.8 At the completion of all applicable overload tests, the crane structures should be thoroughly examined by eye using straight edges and other references, where appropriate, to determine any evidence of buckling, permanent deformation, element out of line, etc. Scale flaking or paint checking may also be indicative of stresses beyond the yield point. Disassemble the boom structure to the state necessary to be assured that all boom elements, extension cylinders or elements, hoist mechanisms, suspension systems, and other load-carrying elements can be inspected.

7.9 Record all pertinent data regarding the test equipment, the crane being tested, and results and observations on the test summary sheet (see Section 9). Record overload test inspection results.

8. Stress Evaluation Notes—Stresses in different parts of cranes are judged acceptable or not on the basis of different criteria of failure. These stress areas may be classed as follows:

8.1 Class I - Uniform Stress Areas—Large areas of nearly uniform stress where exceeding the yield strength or yield point values will produce permanent deformation of the member as a whole. Strength margin:

$$n_I = S_y / S_r \text{ or } S_y / S' \text{ (refer to 8.1.1 for } S'\text{)} \qquad \text{(Eq.2)}$$

$$n_I \geq 1.5 \text{ for rated loads (see Table 2)}$$

TABLE 2—MINIMUM STRENGTH MARGINS

	Class I	Class II	Class III	Class IV
Y (rated loads)	1.5	1.1	1.6	Refer to 8.4
Z (structural integrity)		Observation only		Refer to 8.4

8.1.1 BIAXIAL STRESS AREAS AND TRIAXIAL STRESS—In biaxial stress fields there may be some error if the uniaxial stress given by $S = E\varepsilon$ (see 2.2.2) is compared to tensile yield point to determine the strength margin. The question arises when consideration is given to the theory of failure applicable to the material being tested. Triaxial stresses are not considered here because the third direction cannot be measured with a strain gage.

a. Brittle Materials—The use of $S = E\varepsilon_x$ (when ε_x is measured in the direction of maximum principal strain) presumes the applicability of the maximum strain theory of failure. This is the commonly accepted theory of failure for brittle materials, and results given are valid for materials of this type.

b. Ductile Materials—The distortion energy theory of failure[2] generally is accepted as the performance criterion of ductile materials subjected to biaxial stresses. This assumes that yield failure occurs when the distortion energy under biaxial stress is equal to the distortion energy at yield stress in pure tension. An equivalent uniaxial stress (S′) developing the same distortion energy as the actual biaxial stress is determined for comparison to the yield point (S_y, see 2.2.3) to establish the strength factor against failure. The equivalent stress:

$$S' = \sqrt{\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2} \qquad \text{(Eq.3)}$$

where:

σ_x = maximum principal stress

σ_y = minimum principal stress

The principal stresses are obtained from the principal strain where the direction of principal strain was previously determined.

$$\sigma_x = E(\varepsilon_x + v\varepsilon_y)/(1 - v^2) \qquad \text{(Eq.4)}$$

$$\sigma_y = E(\varepsilon_y - v\varepsilon_x)/(1 - v^2) \qquad \text{(Eq.5)}$$

where:

E = modulus of elasticity

e_x = maximum principal strain

e_y = minimum principal strain

v = Poisson's ratio

Principal strains are obtained by interpreting rosette gage readings on Mohr's circle or other convenient means. Equivalent stress S_ may also be calculated from principal strains by:

$$S' = \frac{E\sqrt{(1-v)^2(\varepsilon_x - \varepsilon_y)^2 + (\varepsilon_x + v\varepsilon_y)(\varepsilon_y + v\varepsilon_x)}}{(1 - v^2)} \qquad \text{(Eq.6)}$$

When three and four gage rosettes are used, the following equations may be used directly to obtain the equivalent stress based on the readings of each of the legs:

Rectangular rosette (Figure 2):

$$S' = \frac{E}{2}\sqrt{\frac{(\varepsilon_a + \varepsilon_c)^2}{(1-v)^2} + 6\left[\frac{(\varepsilon_a - \varepsilon_b)^2 + (\varepsilon_b - \varepsilon_c)^2}{(1+v)^2}\right]} \qquad \text{(Eq.7)}$$

Delta rosette (Figure 2):

$$S' = \frac{E}{3}\sqrt{\frac{(\varepsilon_a + \varepsilon_b + \varepsilon_c)^2}{(1-v)^2} + 6\left[\frac{(\varepsilon_a - \varepsilon_b)^2 + (\varepsilon_b - \varepsilon_c)^2 + (\varepsilon_c + \varepsilon_a)^2}{(1+v)^2}\right]} \qquad \text{(Eq.8)}$$

T-Delta rosette (Figure 2):

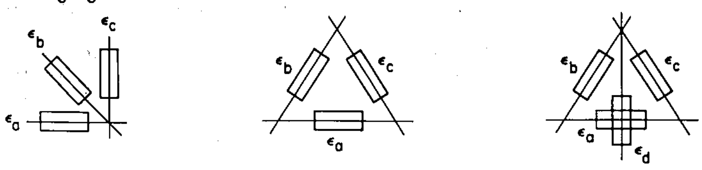
$$S' = \frac{E}{2}\sqrt{\frac{(\varepsilon_a + \varepsilon_d)^2}{(1-v)^2} + 3\left[\frac{(\varepsilon_a - \varepsilon_d)^2 + 4(\varepsilon_b - \varepsilon_c)^2}{(1+v)^2}\right]} \qquad \text{(Eq.9)}$$

c. Ductile Material Approximate Method - In most ductile material biaxial fields, the assumption that the equivalent stress S′ equals $E\varepsilon_x$ will be accurate within 10%. The main factors affecting the accuracy are:

(1) The ratio of minimum to maximum principal stress, σ_y/σ_x.

(2) The ratio of shear yield to tensile yield, τ_o/σ_o.

Figure 3 shows the magnitude of accuracy variance with respect to these two ratios, using Poisson's ratio v -0.285. The plot shows that as the condition approaches biaxial tension or compression, the error can be 25 to 30%. As the condition approaches pure shear, the error may be 0 to 30% depending upon the ratio τ_o/σ_o



RECTANGULAR DELTA T-DELTA

FIGURE 2—RECTANGULAR, DELTA, AND T-DELTA ROSETTES

[2] Joseph Marin, "Mechanical Behavior of Engineering Materials," Englewood, N.J.: Prentice-Hall, Inc., 1962.

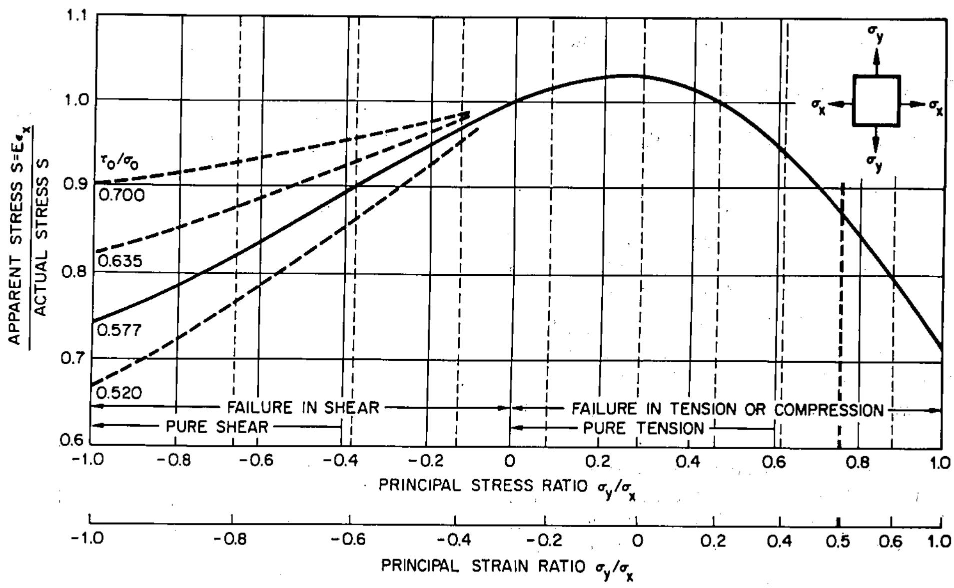


FIGURE 3—RATIO OF APPARENT STRESS TO ACTUAL STRESS VERSUS BIAXIAL STRESS RATIO

The solid curve in Figure 3 is based on the distortion energy theory of failure as compared to $S = E\varepsilon_x$. Distortion energy theory, while most generally correct, will check with the torsion yield test (pure shear) only if $\tau_0/\sigma_0 = 0.577$. For materials in which τ_0/σ_0 does not equal 0.577, the dashed curve lines (which do not correspond with any theory of failure, but only with tensile and torsion yield tests) give some idea of the probable error. If a single gage and $S = E\varepsilon_x$ is to be applied instead of rosettes and more complicated formulation, principal direction must be determined by some other means such as paint checking or (better) brittle lacquer.

8.2 Class II

8.2.1 STRESS CONCENTRATION AREAS—Small areas of high stress surrounded by larger areas of considerably lower stress where exceeding the yield strength or yield point values will not produce permanent deformation of the member as a whole. However, cyclic loading may initiate an incipient fracture at such points. Examples are points of rapid section change such as sharp corners, holes, or weld fillets.

8.2.2 STRENGTH MARGIN

$$n_2 = S_y / S_r \text{ or } S_y / S' \text{ (refer to 8.1.1 for S')}$$
$$n_2 \geq 1.1 \text{ for rated loads (see Table 2)} \quad \text{(Eq.10)}$$

NOTE—Generally, rosettes are not used to measure stress concentrations because of the difficulty involved in evaluating the results with any degree of accuracy.

8.3 Class III

8.3.1 ELASTIC DEFLECTION AREAS—Areas in which failure may be associated with some average stress values less than yield. Examples occur in buckling members or members in which excessive deflection constitutes failure.

$$n_3 \geq 1.6 \text{ rated loads (see Table 2)}$$
$$\text{Refer to 8.3.2 for } n_3 \quad \text{(Eq.11)}$$

8.3.2 COLUMN BUCKLING STRESS—Individual unsupported compression elements of an overall boom or jib, that is, chords or diagonals, require consideration as columns. The following formulas are intended for test evaluation only and are not recommended for design use in determining the strength factor of compression members under test. Consideration must be given to the stiffness of the member, residual stresses in the material, end restraint conditions, and eccentricities in loading. Equation 12 evaluates overall effects:

$$n_3 = \frac{1}{\frac{S_{ra}}{S_{cr}} + \frac{S_{rm} - S_{ra}}{S_y}} \quad \text{(Eq.12)}$$

where:

n_3 = strength margin (derived from an interaction relationship) of the individual member being strain gaged

S_{cr} is determined by equations 13 and 14 as plotted on Figure 4

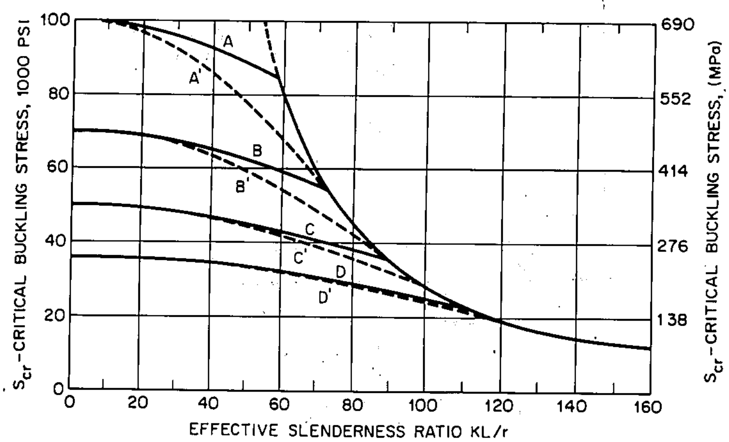


FIGURE 4—CRITICAL BUCKLING STRESS, S_{cr} (TO BE USED WITH EQUATION 15)

At stress levels below the effective proportional limit, axially loaded columns buckle elastically:

$$S_p \geq S_{cr} = \frac{\pi^2 E}{(KL/r)^2} \quad \text{(Eq.13)}$$

At stress levels above the effective proportional limit, axially loaded columns buckle inelastically:

$$S_p < S_{cr} = S_y - \left[\frac{S_p(S_y - S_p)(KL/r)^2}{\pi^2 E}\right] \quad \text{(Eq.14)}$$

The effective proportional limit is defined by:

$$S_p = S_y - S_{RC} \quad \text{(Eq.15)}$$

where:

S_{RC} = maximum residual stress in compression

A value of S_{RC} = 103 MPa (15 000 psi) may be assumed in lieu of specific residual stress information on the following steel materials:

a. Hot finished shapes in the as-rolled condition
b. Quenched and tempered shapes with stress relief heat treatment
c. Cold drawn shapes with stress relief heat treatment
d. Fabricated welded shapes with stress relief heat treatment

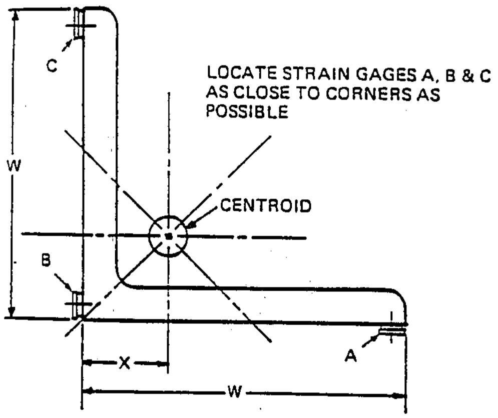
On other steel materials, a value of $S_{RC} = 0.5\ S_y$ may be assumed in lieu of specific residual stress information. Equations 13 and 14 are plotted in Figure 4 for four grades of steel with S_{RC} = 103 MPa (15 000 psi) and also with S_{RC} = $0.5\ S_y$.

The end restraint factor, K, can be calculated by methods outlined in article 2.6 of another report.[3]

The following values may be used in lieu of calculation:

a. For chord members: K = 1
b. For lacing members with full section connection to tubular chords: K = 0.75
c. For lacing members with full section connection to angle or tee chords: K = 0.90
d. For lacing members with reduced section connection to chord: K = 1

In testing compression members, strain gages should be located at the midspan or expected buckling point. When gages are placed at the logical points of highest buckling stress, the highest observed reading may be used for S_{rm} in lieu of computation of the stress plane. When gage locations are asymmetrical with respect to the centroid, the average of the test values cannot be used for S_{ra}. In this case, the test values must be weighted so that S_{ra} represents the value of the stress plane at the centroid. Figure 5 demonstrates a method of weighting test values for an angle section with equal legs. Compression members which are asymmetrical with respect to the centroid, such as structural angles, have different values of radius of gyration (r) in different planes. For evaluation of data obtained from gages in these areas, the determination of S_{cr} must be based on the largest value of KL/r occurring at the chosen area.



$$S_{ra} = \frac{x}{W}(S_A) + \frac{W-2_x}{W}(S_B) + \frac{x}{W}(S_C)$$

FIGURE 5—WEIGHTING TEST DATA FOR AVERAGE AXIAL STRESS

8.4 Class IV - Local Plate Buckling Areas—Plates when subjected to direct compression, bending, and/or shear in their plane may buckle locally before the member as a whole becomes unstable. It is associated with wrinkling (initial buckling) which permits the member to redistribute the load into the stiffer corners. As loading is further increased, the stress in Class IV areas (Figure 6) does not necessarily increase in proportion to the load; however, considerable post buckling strength may remain. Requirements are that Class IV gages return to the dead load readings (see 7.4.4) for all test conditions including overload.

8.5 Elastic Properties of Materials—Recommended values to be used in calculating stress from strain measured at atmospheric temperature are shown in Table 3.

9. Standard Report Format—The following minimum data shall be included in the report.

9.1 Title Page, to include:

a. Date of report
b. Dates of test and personnel involved
c. Description of crane tested
d. Brief description of test instruments used
e. Signed statement that machine was tested and met the minimum requirements of SAE J1063
f. Method of test

9.2 Table of Contents

9.3 Written summary of results on gage test and the structural integrity test.

[3] "Guide to Design Criteria for Metal Compression Members." Column Research Council, Cushion Malloy, Inc., Ann Arbor, MI, 1960.

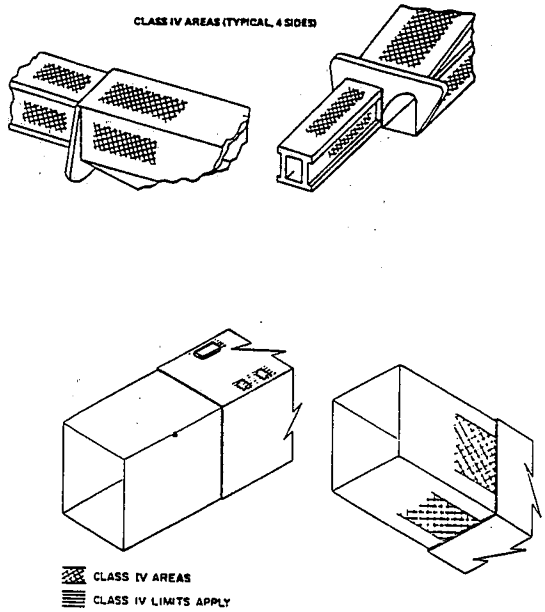


FIGURE 6—CLASS IV AREAS (TYPICAL, 4 SIDES)

TABLE 3—ELASTIC PROPERTIES OF MATERIALS

	Young's Modulus of Elasticity,[1] E x 10⁶ GPa	Young's Modulus of Elasticity,[1] E x 10⁶ psi	Shear Modulus of Rigidity,[1] G x 10⁶ GPa	Shear Modulus of Rigidity,[1] G x 10⁶ psi	Poisson's Ratio v
Steel					
Carbon and alloy structural	207	30	79	11.5	0.285
Cast	207	30	77	11.2	0.265
Stainless	138-193	20-28			0.305
Gray Iron					
Class 20	66-97	9.6-14.0			
Class 60	141-162	20.4-23.5			
Malleable Iron	172	25	76	11	0.271
Modular Iron	165	24	69	10	
Aluminum, Structural	72	10.5	28	4	0.333
Magnesium, Structural	45	6.5			
Titanium, Structural	90-110	13-16			

[1] The modulus of elasticity generally is quoted as a range; the figures listed are toward the high end of the range for conservatism.

The modulus of elasticity of some materials varies widely with chemistry, heat treatment, or stress level. In such cases, a range is listed, and the proper value must be selected for the particular conditions in each case.

9.4 Strain gage location sheet

9.5 Load rating chart as published.

9.6 Tabular summary of test conditions for tests 1 through 11 (Figure 7).

9.7 Column (jib) stress summary sheets for tests 6 through 8 (Figure 8).

9.8 Boom superstructure and carrier stress summary sheets for tests 1 through 9 (Figure 9).

10. Loading Conditions - Test Table—This document covers conventional cranes of the general types shown in Figure 1. The method of test may be applicable to other types, but the test conditions and strength suggested here should be reviewed and perhaps modified to suit the application.

The standard test loading conditions for the principal structural components of cranes are listed in Table 1, together with suggested minimum allowable strength factors for these loadings. Table 1 covers lifting crane hook work for which the number of stress cycles during the expected life of the crane does not require consideration of fatigue endurance limit. The conditions listed simulate the maximum loading imposed on cranes of normal configuration when operating within the range of the manufacturer's published ratings.

TYPICAL SUMMARY FORM

MODEL ____________ DATE ____________

SAE TEST NO.	BOOM LENGTH, FT (m)	BOOM ANGLE, DEG	BOOM RADIUS, FT (m)	JIB LENGTH, FT (m)	JIB OFFSET, DEG	LOAD LB (kg)	SIDE LOAD LB (kg)	SUPER-STRUCTURE POSITION
1a								
1b								
2a								
2b								
3a								
3b								
4a								
4b								
5a								
5b								
6a								
6b								
7a								
7b								
8a								
8b								
9								
10a								
10b								

FIGURE 7—TYPICAL SUMMARY FORM

TYPICAL SUMMARY SHEET (ENGLISH UNITS)

STRESS SUMMARY: BOOM, SUSPENSION, AND CARRIER   SAE TEST NO. 4(a)

MODEL ____________ DATE ____________ PAGE ____ OF ____

GAGE NO.	SW. POS.	DEAD LOAD	DL+ LL	DL+ LL+ SLL	DL+ LL+ SLR	S' MAX EQUIV	Sy YIELD	CL	N MIN
10	95	3.9-	11.1-	12.4-	10.4-	12.4-	29.0	2	2.30
11	96	2.7-	10.5-	12.3-	9.1-	12.3-	29.0	2	2.30
47	78	4.8	30.0	25.0	35.0		100.0	1R	
48	79	4.0	28.0	20.0	35.0		100.0	1R	
49	80	3.0	20.0	5.0	35.0		100.0	1R	
S'		5.6	37.2	28.5	49.0	49.0			2.03
θ		-28.2°	-24.7°	-23.0°	0.0°				
SX		6.2+	41.1-	32.7+	49.0+				
SY		4.8-	31.7-	14.1+	49.0-				
150	50	3.1-	8.8-	3.1-	17.2-	17.2-	65.0	3	
151	51	3.4-	10.9-	3.4	23.5-	23.5-	65.0	3	
152	52	3.0-	9.0-	3.4	20.4-	20.4-	65.0	3	
220	20	0.3	0.3	1.1	0.4	1.1	35.0	1	31.8
221	21	0.5-	3.1-	4.3-	2.2-	4.3-	35.0	1	8.1

FIGURE 8—TYPICAL COLUMN (Jib) SUMMARY FORM (U.S. CUSTOMARY UNITS)

TYPICAL SUMMARY FORM (ENGLISH UNITS)

STRESS SUMMARY: COLUMN (JIB)   SAE TEST NO. 4(a)

MODEL ____________ DATE ____________ PAGE ____ OF ____

GAGE NO.	DISTANCE TO BOOM FOOT	S_{cr}	S_y	DEAD LOAD		SLL		SLR		N MIN
				S_{ra}	S_{rm}	S_{ra}	S_{rm}	S_{ra}	S_{rm}	
154	113.1	58.7	65.0	2.1-	3.5-	0.7+	5.5+	21.6-	23.7-	2.50
155	113.1	58.7	65.0							
156	113.1	58.7	65.0							
165	113.2	58.7	65.0	2.0-	2.2-	27.4-	30.2-	2.8-	3.4-	1.96
166	113.2	58.7	65.0							
167	113.2	58.7	65.0							
168	113.3	58.7	65.0	3.2-	3.8-	26.1-	31.6-	3.2-	3.7-	1.89
169	113.3	58.7	65.0							
170	113.3	58.7	65.0							
150	113.4	58.7	65.0	2.9-	3.1-	1.5+	3.4+	20.8-	23.5-	2.52
151	113.4	58.7	65.0							
152	113.4	58.7	65.0							
P/AVERAGE				2.5-		12.8-		12.1-		

FIGURE 9—TYPICAL BOOM SUPERSTRUCTURE SUMMARY FORM (U.S. CUSTOMARY UNITS)

[redacted]